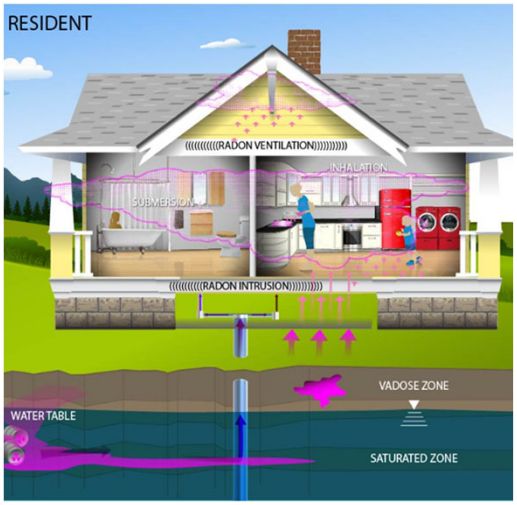

FACTORS AFFECTING THE FRACTIONAL EQUILIBRIUM FACTOR (F_{EQ}) OF RADON (RN-222) AND ITS PROGENY INDOORS

Caitlin Shanahan

1

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2

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3

RVISL CALCULATOR

- Radon Vapor Intrusion Screening Level (RVISL) Calculator
- Establishes RVISLs, preliminary remediation goals (PRGs)
- Covers residential, commercial, and industrial exposure
- Accounts for Rn-222 in groundwater, air, and soil

4

Table 1. Summary Statistics of Current Suggested Indoor Concentrations Limits and Equilibrium Factors (F_{eq}) of Rn-222, Rn-220, and Rn-219

Source	RADON (RN-222)			THORON (RN-220)			ACTINON (RN-219)		
	Concentration (pCi/L)	Concentration (Bq/m3)	F_{eq}	Concentration (pCi/L)	Concentration (Bq/m3)	F_{eq}	Concentration (pCi/L)	Concentration (Bq/m3)	F_{eq}
US Environmental Protection Agency (US EPA)[a]	4	60	0.4	7.5	-	-	-	-	-
Uranium Mill Tailings Radiation Control Act (UMTRCA)[b]	5	185	0.4	7.5	277.5	-	-	-	-
International Commission on Radiological Protection (ICRP) Indoor Standard[c]	5.405	300	0.4	2.703	100	0.1	2.703	100	-
National Council on Radiation Protection and Measurements (NCRP)[d]	8±2	296±74	0.4-0.5	-	-	-	-	-	-
National Institutes of Standards and Technologies (NIST)[e]	2-4	-	0.5	-	-	-	-	-	-
Oak Ridge National Laboratory (ORNL) Resident[f]	-	-	0.8899	-	-	0.2106	-	-	0.8569

Sources are available upon request and/or are referenced in the paper

5

Table 1 (Continued). Summary Statistics of Current Suggested Indoor Concentrations Limits and Equilibrium Factors (F_{eq}) of Rn-222, Rn-220, and Rn-219

Source	RADON (RN-222)			THORON (RN-220)			ACTINON (RN-219)		
	Concentration (pCi/L)	Concentration (Bq/m3)	F_{eq}	Concentration (pCi/L)	Concentration (Bq/m3)	F_{eq}	Concentration (pCi/L)	Concentration (Bq/m3)	F_{eq}
Oak Ridge National Laboratory (ORNL) Commercial[f]	-	-	0.7209	-	-	0.5227	-	-	0.6379
United Nations Scientific Committee on The Effects of Atomic Radiation (UNSCEAR)[g]	-	-	0.2	2	74	0.02	-	-	-
World Health Organization (WHO)[h]	2.703	100	-	-	'	-	-	-	-
European Environment & Health Information System (ENHIS)[i]	1.081	40	-	-	-	-	-	-	-

Sources are available upon request and/or are referenced in the paper

6

TABLE 2. FACTORS INCREASING INDOOR RN-222 FEQ

Factor Type	F_{eq}	Reference
Smoking	0.72	US EPA, 2004, Pgs. 18-25
High Altitude	0.71	Chen & Harley, 2018, Pg. 493-495
Humidity/Rain	0.69 ± 0.18	Acree, 2014, Pgs. 3-5
Smog	0.63 ± 0.15	Chambers et al., 2015, Pgs. 1178-1180
Tighter Construction (concrete, brick, etc.)	0.60 ± 0.24	Collé et al., 1981
Inactivity (4:00 P.M. to 6:00 P.M.)	0.59	Kusuda et al., 1980, Pgs. 1203-1204
High Population Density (greater than or equal to 300 persons/km^2)	0.58	Chen & Harley, 2018, Pg. 492
Increased Emanation Rate	0.56	Kusuda et al., 1980, Pgs. 1202-1205
Underground Workspaces	0.54	Kreuzer and McLaughlin, 2010, Subsection "Health Effects"
Suggested Average Limit	0.4	US EPA, 2004, Pgs. 1&3

*Table 2 exhibits factors that increase the F_{eq} of Rn-222. While minimal data is presented in literature, it is understood that these increases are representative of Rn-220 and Rn-219, as each factor listed increases the incident equilibrium.

7

IMPACT OF SMOKING

Suggested Average Limit	0.4	US EPA, 2004, Pgs. 1&3
Smoking	0.72	US EPA, 2004, Pgs. 18-25

- Chronic smoking: ≥ 15 cigarettes per day
- Chronic smoking increases excess lifetime cancer risk (ELCR) by 16%
- 10 times less comparative risk for non-smokers

8

BIOGEOCHEMICAL EFFECTS

Suggested Average Limit	0.4	US EPA, 2004, Pgs. 1&3
Humidity/Rain	0.69 ± 0.18	Acree, 2014, Pgs. 3-5
High Altitude	0.71	Chen & Harley, 2018, Pg. 493-495

- Rainy-day indoor Rn-222 concentrations up to 6.9 pCi/L or 255.3 Bq/m3
- Acidity of rain causes corrosion and erosion
- Higher Altitude = Thinner Air = Less Plating and More Airborne Rn-222 Progeny

9

LACK OF AIR EXCHANGE

Suggested Average Limit	0.4	US EPA, 2004, Pgs. 1&3
Inactivity (4:00 P.M. to 6:00 P.M.)	0.59	Kusuda et al., 1980, Pgs. 1203-1204
Tighter Construction (concrete, brick, etc.)	0.60 ± 0.24	Collé et al., 1981

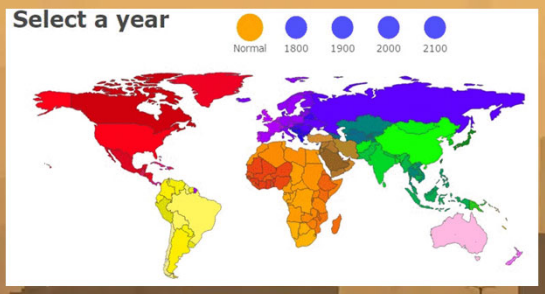
- Porosity and permeability of building materials like concrete lessen air flow
- HVAC usage increases radon concentration
- Less activity means less particle deposition and less air exchange

10

IMPACT OF POPULATION AND SMOG

Suggested Average Limit	0.4	US EPA, 2004, Pgs. 1&3
Population Density (greater than or equal to 300 persons/km²)	0.58	Chen & Harley, 2018, Pg. 492
Smog	0.63 ± 0.15	Chambers et al., 2015, Pgs. 1178-1180

- Smog causes an AQI greater than 30
- Rn-222 progeny adheres to airborne pollutants
- Increases excess lifetime cancer risk (ELCR) and bronchial dose



11

IMPACT OF MINING AND FRACKING

Suggested Average Limit	0.4	US EPA, 2004, Pgs. 1&3
Underground Workspaces	0.54	Kreuzer and McLaughlin, 2010, Subsection "Health Effects"
Increased Emanation Rate	0.56	Kusuda et al., 1980, Pgs. 1202-1205

- Techniques disrupt rock bodies which increases emanation
- Uranium mining increases bronchial dosage by ≥ 15%
- 42% higher Rn-222 concentrations around unconventional wells

12

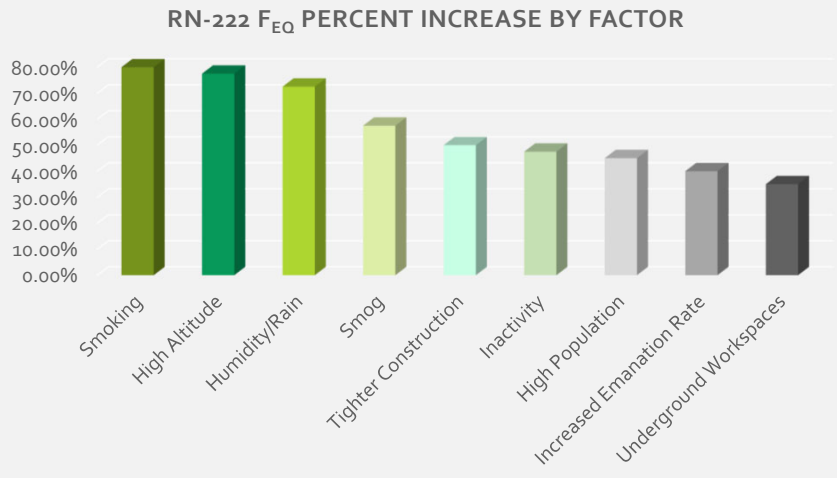
TABLE 3. FACTORS DECREASING INDOOR RN-222 F_{EQ}

Factor Type	F_{eq}	Reference
Hours of High Activity (6:00 A.M. to 4:00 P.M.)	0.27-0.78	Chen & Harley, 2018, Pgs. 493-495
Thermal Spas	0.3	Chen & Harley, 2020, Pg. 345
Sea Level Altitude	0.31 ± 0.09	Nero et al., 1990, Pgs. 60-66
Snow Coverage	0.32	Yamazawa et al., 2005, Pg. 2
Ventilation (open windows, minimal HVAC use, greater sq. ft., etc.)	0.33	Chen & Harley, 2018, Pgs. 493-495
Sparse Population Density (less than or equal to 90 persons/km^2)	0.34 ± 0.12	Chen & Harley, 2018, Pg. 492-493
Loose Construction (wood, gapping, lack of insulation, etc.)	0.36	Collé et al, 1981 and Appleton & Miles 2010, Pgs. 802-803
Tourist Mines and Show Caves	0.39	Chen & Harley, 2020, Pg. 343
Aerosol Particle Plate Out/Deposition	0.39 ± 0.04	Harley et al., 2012, Pgs. 461-462 and Porstendörfer et al.1978, Pgs. 468-472
Suggested Average Limit	0.4	US EPA, 2004, Pgs. 1&3

*Table 3 exhibits factors that decrease the F_{eq} of Rn-222. While minimal data is presented in literature, it is understood that these increases are representative of Rn-220 and Rn-219, as each factor listed increases the incident equilibrium

13

CONCLUSION



The percent increase for each factor is relative to the EPA suggested Rn-222 F_{eq} limit of 0.4. These percentages are based on averages for each factor and can fluctuate given alterations in environment

14

FUTURE WORK

Seasonal impacts of smoking and smog on Rn-222 F_{eq}

Expand research and sampling of Rn-220 and Rn-219

Propose an update to RVISL calculator to consider factors such as smoking and smog for ELCRs and PRGs

15

HELP US OUT

1. Are you aware of a study that assessed equilibrium levels of radon, thoron, and actinon that is not included in this presentation?
   - ➢Yes, it is publicly available
   - ➢Yes, it is not publicly available
   - ➢No
2. If it is publicly available, please provide information on it (e.g., name of government agency, university, company, etc) and how to obtain it (e.g., website, contact name and phone number)
3. What ongoing research, if any, are you aware of regarding radon, thoron, and actinon risk assessment?

16

QUESTIONS?

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17